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THE ROLE OF THE BIG FLARE SYNDROME IN CORRELATIONS OF SOLAR ENE--ETC(U)
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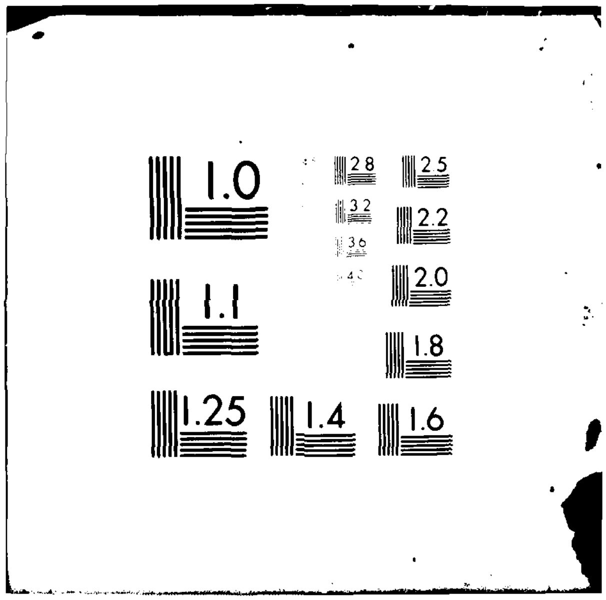
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AFGL-TR-81-0280
ENVIRONMENTAL RESEARCH PAPERS, NO. 754

The Role of the Big Flare Syndrome in Correlations of Solar Energetic Proton Fluxes and Associated Microwave Burst Parameters

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21 September 1981

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FOR THE COMMANDER

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-81-0280	2. GOVT ACCESSION NO. AD A109 806	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THE ROLE OF THE BIG FLARE SYNDROME IN CORRELATIONS OF SOLAR ENERGETIC PROTON FLUXES AND ASSOCIATED MICRO-WAVE BURST PARAMETERS		5. TYPE OF REPORT & PERIOD COVERED Scientific. Interim. 6. PERFORMING ORG. REPORT NUMBER ERP No. 754
7. AUTHOR(s) S.W. Kahler*		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Geophysics Laboratory (PHG) Hanscom AFB Massachusetts 01731		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 46430308
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory (PHG) Hanscom AFB Massachusetts 01731		12. REPORT DATE 21 September 1981 13. NUMBER OF PAGES 32
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

*NRC Research Associate at AF Geophysics Laboratory

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Big flare syndrome
Solar energetic protons
Solar proton fluxes
Microwave burst parameters
Proton-microwave correlations
Particle acceleration processes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In previous studies correlating $E > 10$ MeV proton fluxes and spectra with various associated microwave burst parameters, the resulting high correlations were assumed to reflect a common acceleration process for the protons and the microwave-emitting electrons. We suggest and test an alternative explanation for these correlations, which we term the Big Flare Syndrome (BFS), that states that, statistically, energetic flare phenomena are more intense in larger flares, regardless of the detailed physics. Peak

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20. Abstract (Continued)

1-8Å X-ray fluxes, characteristic of the thermal flare, are correlated with peak proton fluxes to derive correlation coefficients characteristics of the BFS. Of all microwave parameters tested for the 1973-1979 period, only the time-integrated flux densities at 8800 and 15400 MHz may be significantly larger than expected from the BFS. We fail to confirm previous results associating peak proton spectra with peak microwave spectral characteristics, thus finding no evidence that peak microwave fluxes are indicative of proton acceleration. We extend this conclusion to peak hard X-ray correlations. The strongly nonlinear relationship deduced between flare energy and proton production also appears invalid.

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Preface

This work was supported by a Research Associateship from the National Research Council. I wish to acknowledge helpful discussions with P. Bakshi, R. McGuire, and the members of the Solar Radio Section of the Plasmas, Particles and Fields Branch at Air Force Geophysics Laboratory.

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Illustrations

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The Role of the Big Flare Syndrome in Correlations of Solar Energetic Proton Fluxes and Associated Microwave Burst Parameters

1. INTRODUCTION

Our knowledge of the acceleration and propagation of energetic ($E > 10$ MeV) protons in the solar corona is at a primitive stage because of the paucity of unambiguous electromagnetic solar signatures of such protons. Compared to energetic ($E > 10$ keV) electrons, the yields of bremsstrahlung and gyrosynchrontron emission are negligible for the protons. γ-ray-line events and, perhaps, white-light flares are observed signatures of energetic protons at the sun (Ramaty et al, 1980[1]), but there is no evidence to indicate a close association of these phenomena with energetic protons detected in the interplanetary medium. Good correlations of the interplanetary proton events with type II bursts (Svestka and Fritzova-Svestkova, 1974[2]) and with coronal white-light mass ejections (Kahler et al, 1978[3]) have been reported, but these latter phenomena have not been found to correlate with either the spectra or the intensities of the proton events. Thus, the problem remains of

(Received for publication 17 September 1981)

1. Ramaty, R., et al (1980) Energetic particles in solar flares, Solar Flares, P.A. Sturrock (ed.) Colorado Associated University Press, Boulder, Colo., 117.
2. Svestka, Z., and Fritzova-Svestkova, L. (1974) Type II radio bursts and particle acceleration, Solar Phys. 36:417.
3. Kahler, S.W., Hildner, E., and van Hollenbeke, M.A.I. (1978) Prompt solar proton events and coronal mass ejections, Solar Phys. 57:429.

finding an electromagnetic signature that can, in some way, reveal details of the physical processes of proton acceleration.

The association between microwave bursts and interplanetary proton events has been studied for the past two decades. Kundu and Haddock (1960)[4] first reported a correlation between centimeter-wave bursts and polar-cap absorption (PCA) events due to 10-50 MeV protons. From their data they concluded that PCAs are generally also associated with metric type IV bursts, but the occurrence of a type IV burst without an accompanying intense (peak flux greater than 500 s.f.u. over the entire 3-30 cm range) centimeter burst is an insufficient indication of a subsequent PCA. Two fundamental concepts were first articulated by Kundu and Haddock.[4] First, the most reliable radio signature of proton events is to be found in the centimeter, rather than the meter waveband, and second, energetic protons are accelerated by the same process that produces the energetic electrons responsible for the centimeter bursts.

The availability of solar centimeter patrol observations with which one could measure various parameters of solar bursts, such as peak-flux densities, rise times, and time-integrated flux densities, for each of a number of fixed frequencies and the military need to predict significant interplanetary proton events stimulated research into the details of the relationship between centimeter bursts and proton events. These investigations have necessarily been statistical in nature, involving generally 10 or more pairs of proton events and associated centimeter bursts. Three basic approaches have been taken. The first follows that of Kundu and Haddock[4] and seeks a predictor of proton events above a given size threshold. As the best known example of this approach, Castelli et al (1967)[5] proposed that the U-shaped spectrum with high flux densities (> 1000 s. f. u.) at the meter and centimeter wavelengths is characteristic of large proton events. Later, Croom (1971a)[6] claimed that criteria using specific thresholds for peak burst intensity and burst duration at 19 GHz were as effective as the U-burst criteria for event prediction.

The second approach to microwave-proton correlations is more ambitious, with attempts to correlate the peak or time-integrated proton fluxes with various microwave flux parameters. The first attempt of this kind was by Webber (1964),[7] who found a correlation between the time-integrated 10-GHz flux densities and the

4. Kundu, M.R., and Haddock, F.T. (1960) A relation between solar radio emission and polar cap absorption of cosmic noise, Nature 186:610.

5. Castelli, J.P., Aarons, J., and Michael, G.A. (1967) Flux density measurements of radio bursts of proton-producing flares and non proton flares, J. Geophys. Res. 72:5491.

6. Croom, D.L. (1971a) Solar microwave bursts as indicators of the occurrence of solar proton emission, Solar Phys. 19:152.

7. Webber, W.R. (1964) A review of solar cosmic ray events, AAS-NASA Symposium on the Physics of Solar Flares, NASA, Washington, D.C., 215.

and the time-integrated E > 10 MeV proton fluxes for 13 events. Straka and Barron (1969)[8] and Straka (1970)[9] examined the correlations of peak proton fluxes with microwave burst parameters and found the best correlations with time-integrated flux densities, particularly at the lowest observed frequencies of 606 and 1415 MHz. On the other hand, in a similar kind of study Croom (1971b)[10] found that the effective burst duration (the time-integrated flux density divided by the peak flux density) was the best predictor and stressed the use of higher frequencies in the range 5-20 GHz. Newell (1972)[11] found excellent results in correlating the "flash phase" flux densities, integrated from the burst starts to burst maxima, with peak E > 10 MeV proton fluxes. More recent efforts have concentrated on the use of peak-microwave flux densities (Akin'yan et al, 1978a[12]) and time-integrated microwave flux densities at 2.8 GHz (Cliver, 1976[13]) and 9 GHz (Akin'yan et al, 1978b[14]) as predictors of peak proton fluxes. Bakshi and Barron (1980)[15] obtained improved results by using burst flux densities integrated over both the frequency range 606-8800 MHz and the time period of the U shape. These predictive schemes have been "fine-tuned" through the use of solar longitude corrections to the peak proton fluxes (for example, Cliver, 1976[13]) and the use of metric burst criteria (Akin'yan et al, 1978a,[12]b[14]).

In the third approach to proton predictions the microwave data are used to predict the proton energy spectrum at the peak of the proton event. The most prominent example of this approach is the ω_3/ω_2 criterion, where ω_3 is the frequency

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8. Straka, R.M., and Barron, W.R. (1970) Multifrequency solar radio bursts as predictors for proton events, Conference Proceedings, 49, NATO Adv. Group for Aerosp. Res. and Develop., St. Jovite, Canada, 10.
9. Straka, R.M. (1970) The use of solar radio bursts as predictors of proton event magnitudes, AFCRL Space Forecasting Research Note, 2, Air Force Cambridge Res. Lab., Hanscom Air Force Base, Bedford, Mass.
10. Croom, D.L. (1971b) Forecasting the intensity of solar proton events from the time characteristics of solar microwave bursts, Solar Phys. 19:171.
11. Newell, D.T. (1972) Forecasting Peak Proton Flux and PCA Event Magnitudes Using 'flash-phase' Integrated Radio-burst Flux Density, AFCRL-72-0543, Air Force Cambridge, Res. Lab., Hanscom AFB, Bedford, MA AD 751925.
12. Akin'yan, S.T., Alibegov, M.M., Kozlovskiy, V.D., and Chertok, I.M. (1978a) Quantitative identification of proton flares from the characteristics of microwave radio bursts on frequencies of ~9 GHz, Geomagnetism and Aeronomy 18:275.
13. Cliver, E.W. (1976) Parent-flare Emission at 2.8 GHz as a predictor of the Peak Absorption of Polar-cap Events, NELC/TR 2015, Naval Electronics Lab. Cen., San Diego, Calif.
14. Akin'yan, S.T., Fomichev, V.V., and Chertok, I.M. (1978b) Estimates of the intensity of solar protons from the integral parameters of microwave radio bursts, Geomagnetism and Aeronomy 18:395.
15. Bakshi, P., and Barron, W.R. (1980) Prediction of solar flare proton spectrum from radio burst characteristics, Solar-Terrestrial Predictions Proceedings R. F. Donnelly (ed.) 3, National Oceanic and Atmospheric Administration, D-7.

of peak flux density on the centimetric branch of the U burst and ω_2 is the frequency in the decimetric range at the bottom of the U (Bakshi and Barron, 1979[16]). The criterion is that the larger ω_3/ω_2, the flatter the observed interplanetary proton spectrum. A physically similar relationship has been found by Akin'yan et al (1978a).[12] In their study the proton spectra were steeper for those events in which the associated centimetric peak frequency $\omega_3 < 8.8$ GHz than for those with $\omega_3 \geq 8.8$ GHz. This result follows from that of Bakshi and Barron if ω_2 varies relatively little from event to event.[15,16]

The results of the three approaches previously outlined appear as increasingly stronger confirmation of the Kundu and Haddock[4] idea that energetic protons are accelerated by the same process as the energetic electrons responsible for the centimeter bursts. In some of these microwave-proton studies the correlation coefficients calculated for certain microwave parameters have been quite high, of the order of 0.8 (Croom, 1971b[10]), (Straka, 1970[9]) and (Bakshi and Barron, 1979,[16] 1980[15]) or 0.9 (Newell, 1972[11]). Impressed by these various high correlations, some authors have argued their plausibility post hoc on physical grounds, in each case assuming that protons are accelerated along with the energetic radiating electrons. Thus, Croom (1971a)[6] emphasizes that most of the radiated energy from the electrons is in the high-frequency end of the microwave spectrum, Newell (1972)[11] that the flash phase is the most important flare phase for electron acceleration, and Bakshi and Barron (1979)[16] that the flatter the electron spectrum, the higher the peak frequency in the centimeter range.

While these arguments may seem reasonable, particularly in view of the observed high correlations cited above, there are other reasons for expecting that microwave emission may not be a good indication of the proton acceleration process(es). For example, if protons are accelerated in only the second of a two-phase acceleration process (Ramaty et al, 1980[1]) then the impulsive, first-phase electrons producing at least the early stages of the microwave burst may have little to do with the later proton acceleration. Furthermore, if the $\tau \leq 1$ hr coronal injection durations deduced from proton time-intensity profile fits (Ma Sung and Earl, 1978[17]) are indicative of a prolonged acceleration process, one may ask how the peak microwave flux densities or the shape of the microwave spectrum at a particular time in the burst can reveal either the peak flux or the spectrum of the proton event observed in the earth's environment. Conversely, it is difficult to understand how the effective duration time of a microwave burst (Croom, 1971b[10]) can indicate proton intensities when the microwave flux densities are essentially

---

16. Bakshi, P., and Barron, W.R. (1979) Prediction of solar flare proton spectral slope from radio burst data, J. Geophys. Res. 84:131.
17. Ma Sung, L.S., and Earl, J.A. (1978) Interplanetary propagation of flare-associated energetic particles, Astrophys. J. 222:1080.

disregarded. Finally, in an event observed by Helios 2 at 0.5 AU (Bieber et al, 1980[18]), the derived 0.5 MeV electron interplanetary injection profile tracked closely the 7 GHz emission profile, but the 5 MeV proton injection profile was delayed by about 20 min with respect to that of the electrons, suggesting a possible substantial delay between electron and proton acceleration. Thus, we see that while the results of the various microwave-proton correlations suggest that the microwave emission is providing some information about proton acceleration, there are other reasons for expecting little direct coupling between the two processes.

In this paper we pose and attempt to test a hypothesis to explain why, in the face of theoretical difficulties, one obtains favorable correlations between microwave-burst and proton-event parameters. This hypothesis, which is, undoubtedly, implicitly assumed by all workers in the field, we shall call the Big Flare Syndrome (BFS). It can be stated as follows: the larger the energy release in a solar flare, the larger the statistically expected magnitude of any measured flare energy manifestation. The implication of the BFS is that any attempt to correlate over a sample of flares two parameters, each measuring the magnitude of a flare manifestation, should yield a positive result, independent of the detailed physical relationship between the two parameterized phenomena. The usual way in which this association is measured is to correlate the magnitude of one parameter against the magnitude of the second. The microwave burst-proton flux correlations discussed above constitute several such examples. Another is that of Spangler and Shawhan (1974),[19] who found a correlation between the peak-flux densities of 15.4 GHz bursts and the peak fluxes of associated 2-12 Å soft X-ray bursts. In some cases one parameter may be characterized only as "present" or "not detected". In these cases the first parameter is found to be more probably associated with a "present" second parameter as the magnitude of the first is increased. Thus, Svestka (1970)[20] found that the larger a 2-12 Å soft X-ray burst peak intensity, the greater the probability of its association with a particle event detected in space. As another example, Kane (1981)[21] has found that the more intense a type III radio burst, the greater the probability of its association with an impulsive hard X-ray burst. According to the BFS, these correlations per se do not establish a direct physical coupling between

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18. Bieber, J.W., Earl, J.A., Green, G., Kunow, H., Muller-Mellin, R., and Wibberenz, G. (1980) Interplanetary pitch angle scattering and coronal transport of solar energetic particles: new information from Helios, J. Geophys. Res. 85:2313.

19. Spangler, S.R., and Shawhan, S.D. (1974) Short duration solar microwave bursts and associated soft x-ray emission, Solar Phys. 37:189.

20. Svestka, Z. (1970) The phase of particle acceleration in the flare development, Solar Phys. 13:471.

21. Kane, S.R. (1981) Energetic electrons, type III radio bursts and impulsive solar flare x-rays, Astrophys. J. (in press).

the correlated variables. With no additional observational evidence, the physics underlying the 2-12 Å correlations with the 15.4 GHz bursts and with the particle events mentioned above is moot. On the other hand, Kane (1981)[21] has transcended the BFS by marshalling additional observational data involving type III-burst starting frequencies, associated hard X-ray spectra, and good timing agreement between type III bursts and associated hard X-ray bursts to establish a physical relationship between the two phenomena. Additional such arguments are also needed if one is to connect physically the microwave bursts and proton events.

In this paper we examine the correlations between peak prompt proton fluxes and the associated microwave burst parameters for the period June 1973 to August 1979. The purpose of this investigation is several-fold. The first is to test the previous correlation results with a new set of proton events of lower intensity threshold and during a different phase of the solar cycle. The earliest studies used PCA intensities with a particle flux threshold of ~ 2 proton $cm^{-2}\ s^{-1}\ sr^{-1}$ for E > 10 MeV (Newell, 1972[11]) and (Cliver, 1976[13]). Later studies used published data from the JHU/APL proton detectors on the Explorers 34, 41, and 43 with an E > 10 MeV event threshold of ~ 0.3 protons $s^{-1}\ cm^{-2}\ sr^{-1}$. The equivalent threshold for events of this study observed with the GSFC detectors on the IMP 7 and 8 spacecraft is lower than that of the JHU/APL detectors by a factor of about 10 to 30. The use of the larger dynamic range of proton fluxes will provide a more stringent test of the correlations found by previous authors.

Another goal of the study is to find from those examined the optimum microwave correlation parameter(s) and see whether it correlates significantly better with peak proton fluxes than would be expected from the BFS. A well-correlated parameter may then provide a useful measure of the proton acceleration process, but, on the other hand, a lack of such parameters can indicate that the proton and electron acceleration processes are not closely coupled.

To get a measure of the degree of correlation due to the BFS we correlate peak soft X-ray fluxes with peak proton fluxes under the assumption that the soft X-ray emission from thermal flare plasma is independent of the nonthermal proton acceleration process. Only Svestka (1970)[20] appears to have suggested a rationale for a soft X-ray correlation with proton fluxes. He argued that all particle acceleration takes place during the impulsive phase, with the energetic particles drawn from those of the thermal plasma. Thus, the energetic electron and proton production should be proportional to the soft X-ray emission from the thermal plasma. Based on this assumption, Kuck (1969)[22] found a correlation coefficient of 0.85 between the E > 25 MeV peak proton flux and the time-integrated 0.5-5 Å X-ray flux for 16 events. However, Svestka later abandoned this argument (Svestka and Fritzova-Svestkova, 1974[2]) in favor of a two or three-stage acceleration process in

22. Kuck, G.A. (1969) Prediction of polar cap absorption events, Technical Note WLRTH 69-8, Air Force Weapons Lab., Kirtland AFB, New Mexico.

which energetic protons are produced in a shock wave following the impulsive phase. Furthermore, there is no evidence to indicate that energetic protons are drawn from the soft X-ray emitting thermal plasma that is contained in coronal magnetic loops (Moore et al, 1980[23]). On the contrary, Lin and Hudson (1976)[24] maintain that the thermal plasma is the energy sink rather than the particle source of the energetic electrons of the impulsive phase, but Datlowe (1975)[25] found that energy sources other than energetic electrons were needed. In any case, the peak soft X-ray emission is not simply proportional to the energy content or number of electrons in the thermal plasma, but rather dependent on the emission measure distribution, dn_e^2V/dT, where n_e is the electron density, V, the volume, and T, the temperature that obtains for a particular time in a given flare (Moore et al, 1980[23]). The result is that we have no reason to think that a correlation between the soft X-ray flux, due to the thermal phase of a flare, and energetic protons, produced nonthermally in the flare, should be due to anything other than the BFS. Consequently, we include a correlation of peak 1-8 Å fluxes with peak proton fluxes as a means of obtaining correlation coefficients characteristic of the BFS and ask whether any of the tested microwave parameters result in correlation coefficients significantly higher than those obtained with the 1-8 Å fluxes.

We use peak prompt proton fluxes in this study as the proton parameter characterizing each event. The earliest correlation studies used the time-integrated fluxes as the proton parameter, but Straka and Barron (1970)[8] and nearly all subsequent investigators have used the more easily obtained and more militarily important peak fluxes. From the point of view of understanding proton acceleration, what we want to measure is some parameter that can be related either to the total number of protons, N(E), of a given energy E accelerated in the event, or to the rate at which energetic protons are produced, dN(E)/dt. A recent approach to modeling proton propagation involves a Gaussian temporal profile for proton injection at the sun, followed by focused diffusion (Earl, 1976[26]) in the interplanetary medium. Focused diffusion describes the combined effects of scattering from interplanetary magnetic field fluctuations and focusing due to the divergence of the interplanetary field with distance from the sun. The key parameter in this theory is V/AL, where V is the particle velocity; A, the intensity of the pitch-angle scattering function; and L, the interplanetary magnetic-field scale length. When

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23. Moore, R., et al (1980) The thermal x-ray flare plasma, Solar Flares P.A. Sturrock (ed.), Colorado Associated University Press, Boulder, Colo. 341.

24. Lin, R.P., and Hudson, H.S. (1976) Non-thermal processes in large solar flares, Solar Phys. **50**:153.

25. Datlowe, D.W. (1975) The relationship between hard and soft x-ray bursts observed by OSO 7, Solar Gamma -X-, and EUV Radiation S.R. Kane (ed.) D. Reidel Publishing Co., Dordrecht-Holland, 191.

26. Earl, J.A. (1976) Nondiffusive propagation of cosmic rays in the solar system and in extragalactic radio sources, Astrophys. J. **206**:301.

$V/AL \gg 1$, the propagation takes place as a coherent pulse of temporal width σ, where σ is the width of the Gaussian injection profile. With increasing distance from the sun, L increases, and the regime of focused diffusion, wherein $V/AL \leq 1$ is reached. The smaller V/AL, the smaller the ratio of the coherent pulse to the diffusive wake. Detailed fitting by Ma Sung and Earl (1978)[17] to well-connected (W20° to W100°) 30-50 MeV proton events revealed that V/AL ranged from 0.06 to 0.20 for 17 of 18 events, indicating a clear dominance of the diffusion regime. In addition, for 16 of the 18 events $\sigma \leq 0.9$ h, a period short compared to the typical 3-5 h interval from proton event onset to maximum. Since, at the time of the peak, the proton flux is due mostly, if not entirely, to the diffusive wake accumulated from the entire Gaussian coherent pulse, and the pulse width is small compared to the time for the flux to reach maximum, the peak flux should be roughly proportional to N(E) for each well-connected event. More importantly, for poorly-connected events in which the coherent pulse is not observed at the earth, the magnitude of the observed diffusive component, corrected for longitudinal distance from W50°, again will be proportional to N(E) to first order. This result also appears to hold when the pitch-angle scattering equation is treated numerically (Owens and Gombosi, 1981[27]). Proton intensity profiles derived for $\alpha^{-1} = 0.08$ and 0.12 (nearly equivalent to Earl's parameter V/AL) show peak intensities I_p varying by a factor of only ~1.5. We conclude, therefore, that within the context of the focused diffusion model the peak proton fluxes, corrected for flare longitude, provide the best usable index of the time-integrated proton flux injected into interplanetary space.

In the next section we discuss the selection and analysis of the data. The results of the correlations are presented in the following section and a discussion of the implications of the results follows in the final section.

2. DATA ANALYSIS

2.1 Selection of the Data

Prompt proton events were selected from the 20-40 and 40-80 MeV proton fluxes observed with the GSFC E vs dE/dx detectors on the IMP 7 and 8 spacecraft. Monthly plots of hourly averages of proton fluxes published in the Solar Geophysical Data bulletins (1973-1981)[28] and supplementary plots provided by R. McGuire[29] of GSFC were used. The time frame began with June 1973, the

27. Owens, A.J., and Gombosi, T.I. (1981) The inapplicability of spatial diffusion models for solar cosmic rays, Astrophys. J. 245:328.
28. Solar-Geophysical Data (1973-1981) Helen Coffey (ed.) National Oceanic and Atmospheric Administration, Boulder, Colo.
29. McGuire, R.E. (1980) Private communication.

first month following the last published plots of the frequently used JHU/APL Explorer proton data. The study interval was terminated with August 1979, the most recent month for which comprehensive Hα flare reports were then available. For each proton event the times of microwave and metric bursts and Hα flares were compared with the proton event onsets to determine the proton flare association. Only those proton events for which a well-associated disk flare could be found were used in the study. The Hα flare sizes and longitudes and associated proton and microwave data are listed in Table 1.

2.2 The Proton Data

For each selected event the peak flux of the prompt component was first corrected for background and any previous event fluxes. The resulting peak 20-40 MeV fluxes in units of protons cm^{-2} sr^{-1} s^{-1} MeV^{-1} are listed in Table 1 with the corresponding values of the differential power-law spectral exponents, γ, derived from the 20-40 and 40-80 MeV fluxes. A longitude correction then was applied to each peak flux value. As shown in Figure 1, the correction was derived by a least-squares fit to the log I_p vs $\Delta\theta$ distributions, where $\Delta\theta$ is the angular distance of the flare from W50^o, the region of apparent optimum connection to the earth (van Hollenbeke et al, 1975[30]). The derived multiplicative corrections to I_p were exp (1.60 $\Delta\theta$) and exp (1.59 $\Delta\theta$), where $\Delta\theta$ is measured in radians, for the 20-40 MeV and 40-80 MeV data, respectively. In principle, one should use the number of events per longitude interval for such a correction if the slope of the event-size distribution is the same for all longitudes. The results of Figure 18 of van Hollenbeke et al (1975)[30] suggest a smaller correction of only exp (0.69 $\Delta\theta$). However, our events show not only a decrease in number with increasing $\Delta\theta$, but also a decrease in average I_p, so we use the larger values. The corrections used here are much smaller than those employed earlier, for example, exp (3 $\Delta\theta$) by Cliver (1976)[13]. With the large dynamic range in I_p, the result of an inappropriate correction factor should have only minimal effect on the correlation coefficients (Barron and Bakshi, 1980[31]). In fact, the high correlation coefficients of several early investigations, (Straka, 1970[9]) and (Croom, 1971b[10]), were obtained with no longitudinal corrections to the peak proton fluxes.

For a typical γ = 3 proton power-law spectrum the minimum detectable flux of the GSFC 20-80 MeV detectors on IMPs 7 and 8 is a factor of 10 to 30 times lower than that of the JHU/APL SPME on the earlier Explorer series. Although

30. Van Hollenbeke, M.A.I., Ma Sung, L.S., and McDonald, F.B. (1975) The variation of solar proton energy spectra and size distribution with heliolongitude, Solar Phys. 41:189.

31. Barron, W.R., and Bakshi, P. (1980) Application of integrated radio burst fluxes to the prediction of solar energetic proton flux increases, Solar-Terrestrial Predictions Proceedings R.F. Donnelly (ed.) 3, National Oceanic and Atmospheric Administration, D-1.

Table 1. Proton Event List

Event	Date	Hα	Long	I_{20-40}	γ	μ Type	t_{peak}(UT)	ω_p(MHz)	F_p(S.F.U.)
1	Jul 29, 73	3B	E45	1.5(-2)	1.55	C	1334	1415	206
2	Sep 7, 73	3B	W47	1.6(-1)	1.40	C	1200	4000	350
3	Oct 27, 73	2B	E55	2.5(-4)	2.55	C	1602	1415	80
4	Nov 3, 73	2N	W85	4 (-2)	2.60	U	0017	5000	350
5	Jul 4, 74	2B	W08	1.6(-1)	3.80	U*	1354	≥35000	7000
6	Jul 5, 74	-N	W20	1.8(0)	4.85	U	1204	7000	450
7	Sep 10, 74	2B	E61	4.5(-1)	3.32	U*	2140	9100	9700
8	Sep 19, 74	2N	W62	6 (-1)	2.50	U*	2240	7000	3300
9	Sep 23, 74	-F	W66	1.3(-1)	1.85	U*	1201	1415	2500
10	Oct 11, 74	1N	E02	1.0(-3)	2.93	U*	0329	9100	1700
11	Nov 5, 74	1N	W78	5.5(-1)	2.85	U*	1535	≥35000	2000
12	Dec 22, 74	1N	E14	9 (-4)	3.72	Uncl.	1610	15400	26
13	Dec 25, 74	1B	W26	8 (-4)	4.47	U	1917	1415	70
14	Aug 21, 75	1B	W74	6 (-2)	2.45	U*	1520	≥35000	2200
15	Aug 22, 75	1B	W81	1.0(-1)	2.32	U	0117	9500	600
16	Nov 21, 75	1B	W21	4 (-3)	3.32	C	0619	2000	460
17	Mar 23, 76	-B	E90	1.3(-3)	0.53	U*	0845	≥8800	1400
18	Mar 28, 76	1B	E28	4.5(-3)	2.49	U*	1934	8800	3700
19	Apr 30, 76	1B	W46	2.3(0)	2.35	U*	2109	8800	2700
20	Sep 7, 77	-	E90	3.0(-2)	3.91	U*	2243	8800	2100
21	Sep 16, 77	2N	W20	5 (-1)	2.48	Flat	2308	1415	2400
22	Sep 19, 77	3B	W57	3.5(0)	2.81	U*	1036	≥15000	3720
23	Oct 6, 77	1N	W59	7 (-4)	3.81	U	0433	8800	250
24	Oct 12, 77	1B	W02	5 (-2)	2.64	U*	0152	8800	1850
25	Nov 22, 77	2B	W40	4 (0)	2.00	U*	1005	8800	4800

Table 1. Proton Event List (Continued)

Event	Date	Hα	Long	I_{20-40}	γ	μ Type	t_{peak}(UT)	ω_p(MHz)	F_p(S.F.U.)
26	Dec 27, 77	1N	W79	9 (-3)	3.49	C	1110	3100	155
27	Jan 1, 78	2N	E06	4 (-2)	2.00	Uncl.	2154	2700	600
28	Jan 8, 78	2B	W85	8 (-3)	3.86	U*	0714	≥9100	1400
29	Feb 13, 78	1N	W20	8 (0)	4.00	C	0202	2700	740
30	Feb 25, 78	1B	W21	9 (-3)	3.03	U	1451	15000	330
31	Apr 8, 78	2B	W11	1.2(-2)	3.32	G	0228	500	19000
32	Apr 11, 78	3B	W56	8 (-1)	2.32	U*	1407	5000	2130
33	Apr 28, 78	3B	E38	2.5(0)	3.21	U*	1329	8800	7530
34	May 7, 78	1N	W72	1.0(0)	1.52	U*	0330	8800	3450
35	May 31, 78	3B	W43	7 (-2)	3.32	C	1043	930	790
36	Jul 11, 78	2B	E45	4.3(-2)	3.26	U*	1053	8800	18500
37	Sep 23, 78	3B	W50	1.0(1)	3.32	Uncl.	1002	8400	680
38	Oct 1, 78	2N	E57	4 (-3)	2.32	Flat	0720	3000	260
39	Oct 9, 78	1B	W61	2.5(-1)	3.16	U	1951	8800	415
40	Oct 13, 78	2B	W01	4 (-3)	1.62	U	1238	7000	500
41	Nov 10, 78	2N	E01	5 (-2)	5.26	None	~0120	-	-
42	Jan 5, 79	-N	E54	9 (-4)	2.59	None	~0020	-	-
43	Jan 21, 79	-B	W85	6 (-4)	2.59	C	1314	2700	145
44	Feb 16, 79	3B	E59	2.2(-2)	1.88	Flat	0151	35000	850
45	Mar 1, 79	3N	E58	2.5(-2)	2.84	U	1017	5000	~500
46	Apr 27, 79	1B	E17	4 (-4)	2.32	U*	0647	17000	3900
47	Jun 5, 79	2B	E14	2.2(0)	6.78	C	0534	8800	4300
48	Jun 18, 79	1N	W65	2.6(-4)	3.12	U	0624	1415	100
49	Aug 18, 79	-N	E17	4.5(0)	3.17	U*	1410	≥15400	1390
50	Aug 21, 79	2B	W40	3.0(0)	1.59	G	0615	500	350

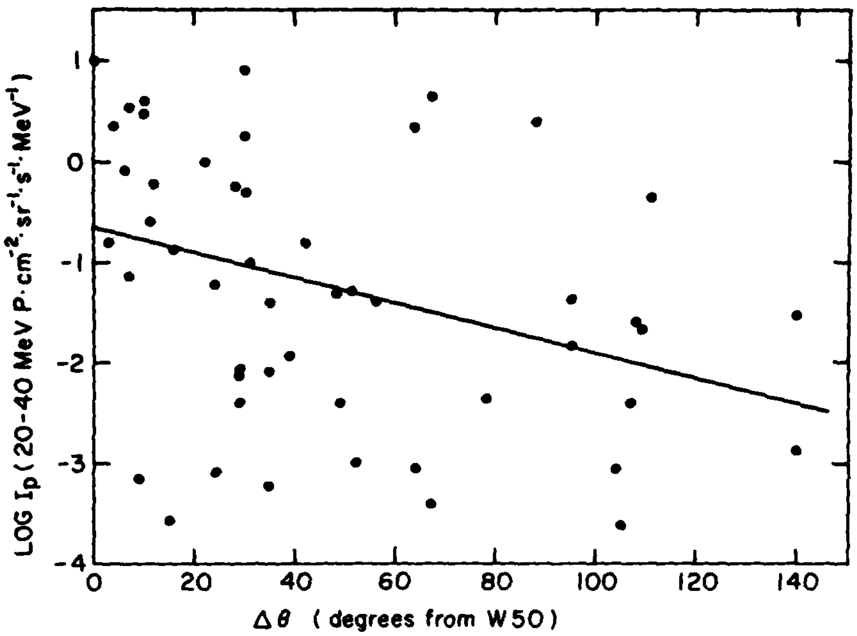

Figure 1. The Solar Longitude Correction for the 20-40 MeV Peak Proton Fluxes, I_p. For each event log I_p is plotted as a function of $\Delta\theta$, the angular distance from W50°. The least-squares best fit is $I_p \sim \exp(-1.604\ \Delta\theta)$, where $\Delta\theta$ is in radians.

more sensitive, the GSFC detectors have also saturated during several events used in this study (McGuire, 1980[29]). This will most likely result in an under-estimate of the flux for the largest events, but we have included these events in the study in order to get the largest possible dynamic range of proton event fluxes. Nine of the events of Table 1 have 20-40 MeV fluxes exceeding 2 protons cm^{-2} s^{-1} MeV^{-1} and are therefore probably saturated to some degree. In those parts of this study involving proton spectra, the spectra of the large events were obtained from the hourly averages of the 15-96 MeV proton channels of the JHU/APL Charged Particle Measurements Experiments (CPME) on the IMPs 7 and 8 (Space Development Department, 1977[32]). For those events the CPME values of γ were slightly lower or comparable to those obtained from the GSFC experiment data.

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32. Space Development Department (1977) Instrumentation developed by the Johns Hopkins University Applied Physics Laboratory for non-APL spacecraft, SD0-4100, The Johns Hopkins University, Laurel, Maryland.

2.3 The Microwave Events

Microwave data for each proton-associated flare of Table 1 were taken from Solar Geophysical Data (1974-1981).[28] The shape of the microwave spectrum near the burst maximum was obtained by plotting peak fluxes of all reported frequencies in the range ~100 to 35000 MHz. In cases of substantial disagreement of peak fluxes among several observatories with comparable frequencies the stations of Sagamore Hill, Manila, and Athens were given preference in deciding the shape of the spectrum, the peak frequency, ω_p, and peak flux densities, F_p. In the cases of several reported bursts in the same event, the largest burst was used. The spread in peak times for the different frequencies used, Δt, was less than 9 min for all events except number 20, for which it was 28 min. Two events, numbers 41 and 42, were associated with no reported radio bursts. The average Δt for the remaining 47 events was 3.16 min. Part of the dispersion in the peak times may be due to genuine differences in those times among different frequencies, but it is clear that timing errors at different observatories are also a major factor in the resulting magnitude of Δt. The resulting composite spectra may therefore be considered a reasonable representation of the instantaneous peak spectrum. The spectral category (Castelli and Guidice, 1976[33]) of G (flux density decreasing with increasing frequency), C (single spectral maximum in the centimeter range), U* (Castelli U-burst), U (U burst, but less than 1000 s.f.u. at the centimeter peak), Flat or Unclassified, is listed in Table 1 along with the peak frequency and flux density for each event. Examples of a U* and a C event are shown in Figure 2. In cases with the microwave spectrum increasing at the highest observed frequency, ω_p is indicated as a lower limit in Table 1. Assuming the peak to be about half an octave above ω_p, ω_3 was then taken as $\sqrt{2}\,\omega_p$.

The three parameters of F_p, the peak flux density; Fdt, the time-integrated flux density; and Tm, the effective duration time defined by $\int F dt / F_p$, have been obtained for each event, where possible, for f = 1415, 2695, 8800, and 15400 MHz. 2695 and 8800 MHz correspond to the 10 and 3 cm wavelengths frequently used in proton-microwave correlation studies. The value of $\int F dt$ was derived by taking the product of the reported mean flux density $\bar{F}$ and the event duration T. When the burst was accompanied by a gradual-rise-and-fall (GRF), a precursor, or a post-burst increase (PBI) event, the accompanying event was included in the calculation of $\int F dt$, but not in the calculation of Tm. In some cases F_p was listed, but not $\bar{F}$ or T. In others, flux densities at nearby frequencies were substituted for missing standard frequencies (for example, the 3100 MHz values for the 2695 MHz values). F_p at each frequency was taken as 3 s.f.u. for events 41 and 42.

33. Castelli, J.P. and Guidice, D.A. (1976) Impact of current solar radio patrol observations, Vistas in Astronomy 19:355.

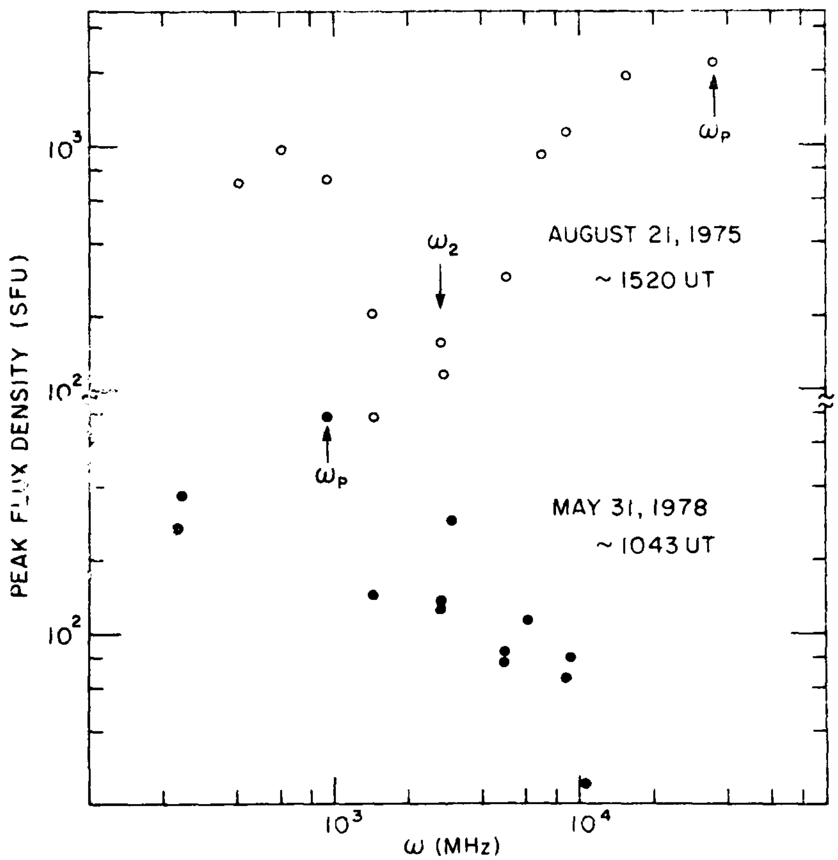

Figure 2. Two Examples of the Microwave Bursts of Table 1. The event of 21 August is a Castelli U-burst; the event of 31 May is a C burst. ω_p is the peak frequency, while ω_2 (the decimetric-band minimum in U bursts) is used in the ω_3/ω_2 relationship of Figure 5.

Uncertainties in F_p and $\int F dt$ were estimated by comparing reports of different observatories with similar frequencies for common microwave bursts. Matching reports within the frequency ranges 2695-3100 and 8800-9100 MHz for parts of years 1974 and 1978, we found that the 1-σ variations among different observatories were factors of 1.15 for F_p and 1.7 for $\int F dt$. These variations reflect only the disagreement among observatories and not any possible systematic errors.

Newell (1972)[11] used 1/3 $F_p t_r$, where t_r is the time from start to peak of the microwave burst, for an approximate value of the integrated-flux density in the rising portion of an impulsive burst. We have used log $F_p t_r$ as the test parameter at 2695 and 8800 MHz for those events categorized as Simple 2, Complex, or Great Burst. Events of other categories or with $t_r > 30$ min were not used for

that phase of the study. The microwave time-integrated flux density following the impulsive phase was also used as a parameter. For those events log $(\bar{F}T - 2/3\,F_p t_r)$ was used as the microwave variable.

2.4 The Soft X-ray Events

Peak 1-8 Å X-ray fluxes of proton flares were taken from the published Solrad-9 data for events in 1973 and from the SMS/GOES data (Donnelly et al, 1977[34]) for events from 1974 to 1979 (Solar-Geophysical Data, 1974-1980[32]). The Solrad-9 peak fluxes were multiplied by a factor of 2 to make them comparable to the SMS/GOES fluxes (Kreplin et al, 1977[35]).

3. RESULTS

3.1 Peak Proton Fluxes

The correlation coefficients for the microwave parameters with the 20-40 and 40-80 MeV longitude-corrected peak proton fluxes are shown in Table 2. The number of 15400 MHz events is lower than those at other frequencies due primarily to the more limited observations at that frequency. Because the durations and average flux densities are not given for some events, the number of events in the peak flux-density category is more than that for the time-integrated flux-density category for each frequency. Differences between the correlation coefficients for the two proton energy ranges are small, reflecting the fact that the range of differences between the two proton fluxes for individual events is far smaller than the range of flux values for all events. They suggest that very similar correlation coefficients would be obtained using lower ($E > 10$ MeV, for example) or higher energy ranges.

The correlation coefficients range from 0.30 to 0.65, with those of the 1-8 Å X-rays, used here as the assumed benchmark of the BFS, at ~0.48. All the correlations are significant at the 95 percent confidence level or better except for that of Tm at 15400 MHz. At each frequency the worst correlation is found for the effective duration, T_m, for which Croom (1971b)[10] found $r = 0.73$, using 32 data points of 30-60 MeV peak proton fluxes and microwave durations at an unspecified frequency. Another poor parameter is the flash-phase integrated flux density, $F_p t_r$, advocated by Newell (1972).[11] His correlation coefficients for the range 2695 to

34. Donnelly, R.F., Grubb, R.N., and Cowley, F.C. (1977) Solar x-ray measurements from SMS-1, SMS-2, and GOES-1. Information for data users, NOAA Technical Memorandum ERL SEL-48, Space Environment Laboratory, Boulder, Colorado.

35. Kreplin, R.W., Dere, K.P., Horan, D.M., and Meekins, J.F. (1977) The solar spectrum below 10 Å, The Solar Output and Its Variation O.R. White (ed.) Colorado Associated University Press, Boulder, Colorado, 287.

Table 2. Correlation Coefficients of Various Microwave Parameters and 1-8 Å X-Ray Fluxes With Peak Proton Fluxes

Frequency (MHz)	Parameter	Events	r	
			20-40 MeV	40-80 MeV
1415	F_p	48	0.43	0.43
	$\int F dt$	45	0.43	0.42
	Tm	45	0.37	0.38
2695	F_p	49	0.52	0.54
	$\int F dt$	44	0.52	0.50
	$F_p t_r$	39	0.37	0.39
	Tm	44	0.30	0.31
8800	F_p	48	0.53	0.55
	$\int F dt$	45	0.64	0.65
	$F_p t_r$	38	0.47	0.48
	$\overline{F}T - 2/3\ F_p t_r$	38	0.56	0.56
	Tm	45	0.46	0.48
15400	F_p	27	0.56	0.56
	$\int F dt$	20	0.63	0.64
	Tm	20	0.32	0.38
1-8 Å X-Rays	F_p	36	0.47	0.50

8800 MHz were r ≈ 0.9, far higher than the values obtained here for the same frequencies. The use of the flux density integrated over all of each event except the flash phase (that is, $\overline{F}T - 2/3\ F_p t_r$) at 8800 MHz, essentially the antithesis of Newell's claim for the importance of the flash phase, yielded a somewhat better correlation that that of the flash phase itself. One difficulty with the use of the flash-phase parameter is that the flash phase does not always coincide with the

occurrence of the peak microwave flux density. Furthermore, Newell's arithmetic approximation of 1/3 $F_p t_r$ for the integrated flux density in the rise portion of the flash phase may also be rather poor for individual cases, although he obtained good results with its use. Nevertheless, the present results show that neither the effective duration nor the flash-phase integrated flux density correlates well with the peak proton flux, and the use of the non-flash phase integrated flux density is only slightly better than the correlation due to the BFS. The correlations of the peak flux densities (Figure 3) are also comparable to or only slightly higher than those obtained for the assumed BFS correlation of the 1-8 Å peak fluxes.

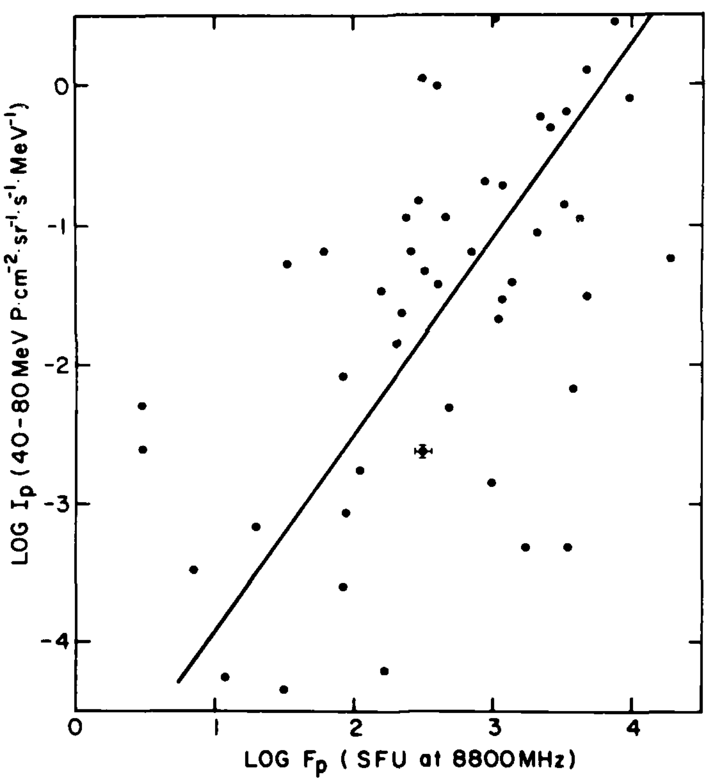

Figure 3. Longitude-corrected Peak 40-80 MeV Proton Fluxes Plotted Against Corresponding Peak 8800 MHz Flux Densities. The uncertainty in F_p was derived from a study of bursts reported at adjacent frequencies in 1974 and 1978. The least-squares best fit is $I_p = 4.75\ 10^{-6}\ F_p^{1.41}$, but the scatter is considerable (r = 0.55). There is no evidence of a microwave threshold for proton production.

The parameters, which may exceed significantly the BFS level of correlation, are the time-integrated flux densities $\int Fdt$ at 8800 and 15400 MHz. The plot of the 8800 MHz integrated flux densities and the longitude-corrected 40-80 MeV peak proton fluxes is shown in Figure 4.

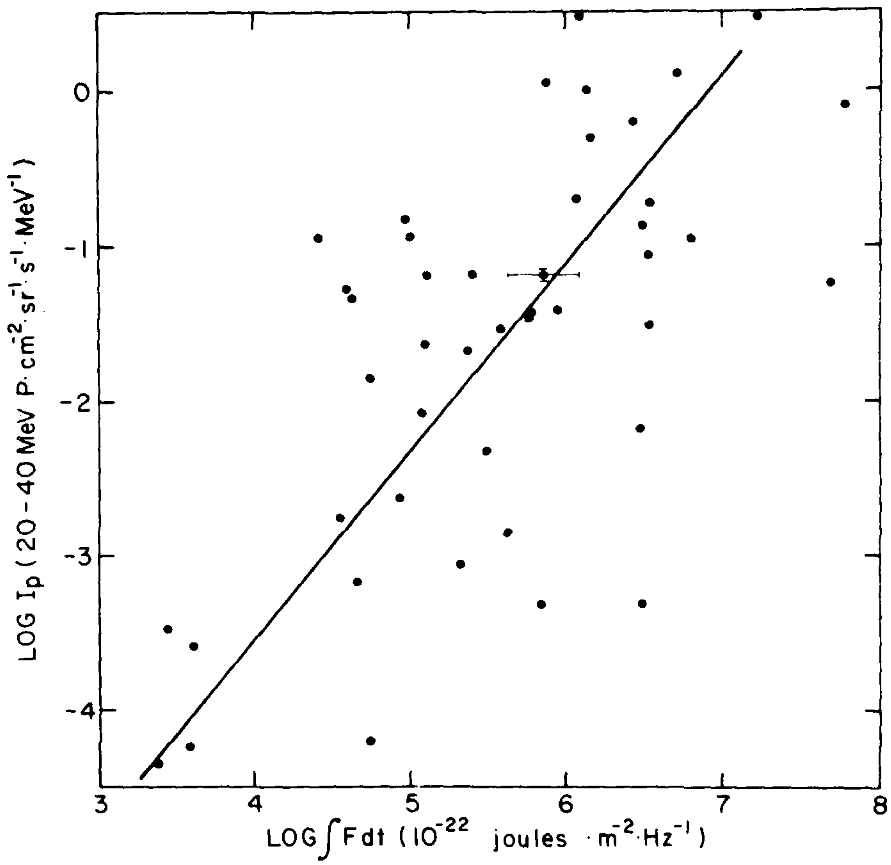

Figure 4. Longitude-corrected Peak 40-80 MeV Proton Fluxes Plotted Against $\int Fdt$ at 8800 MHz. The uncertainty in $\int Fdt$ was derived from a study of bursts reported at adjacent frequencies in 1974 and 1978. The best fit is $I_p = 3.43\ 10^{-9}\ (\int Fdt)^{1.2225}$ where I_p is in protons $cm^{-2}\ sr^{-1}\ s^{-1}\ MeV^{-1}$ and $\int Fdt$ in $10^{-22}\ W\ m^{-2}\ Hz^{-1}$.

3.2 Peak Proton Spectra

We have also tested the proton energy spectral prediction criteria of Bakshi and Barron (1979)[16] and of Akin'yan et al (1978a).[12] A plot of the differential power-law spectral index γ against ω_3/ω_2 for the U and U* bursts is shown in Figure 5. Event 20 was not used because of the large Δt. Note also that γ is derived from fluxes uncorrected for solar longitude. The curved line in the plot is the best fit, converted from their integral spectral exponent plot, derived by Bakshi and Barron for their events.[15, 16] We find no significant correlation between γ and ω_3/ω_2 for either the total data sample of 30 events (r = -0.07) or those 20 events with peak 20-40 MeV proton fluxes greater than 10^{-2} proton cm^{-2} sr^{-1} s^{-1} MeV^{-1} comparable to the Bakshi and Barron sample[15, 16] (r = 0.14), or the 20 U* events (r = 0.13). Similarly, a plot of ω_3 against γ for the U, U*, and C bursts also shows no indication (r = -0.01) of the correlations obtained by Bakshi and Barron[15, 16] and by Akin'yan et al.[12, 14] This is also the case if one excludes C bursts from the sample. Our examination of the data relevant to a connection between the spectral slopes of the microwave events and the spectra of the associated proton events yields no evidence for such a connection.

3.3 Peak Microwave Spectra

A case in which we do find a positive correlation (r = 0.58) is that of F_p versus ω_p shown in Figure 6. The best-fit slope to the data is $F_p \sim \omega_p^{1.5}$, in reasonable agreement with the $F_p \sim \omega_p^2$ found by Furst (1971)[36] for more than 1000 bursts. The same qualitative result that high peak frequencies are associated with larger peak fluxes was also derived for ~1800 C-type bursts by Guidice and Castelli (1975).[37]

4. DISCUSSION

Using the 1-8 Å peak fluxes as the control variable indicative of the correlation due to the BFS, we find that only the time-integrated flux densities at 8800 and 15400 MHz appear as candidate variables for a good measure of the total number of accelerated protons. The effective duration, Tm (Croom, 1971b[10]), the flash-phase flux density, $F_p t_r$ (Newell, 1972[11]), and the time-integrated flux density at 1415 MHz (Straka, 1970[9]) yielded lower correlation coefficients than did the 1-8 Å

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36. Furst, E. (1971) A statistical research on solar microwave bursts, Solar Phys. 18:84.
37. Guidice, D.A., and Castelli, J.P. (1975) Spectral distributions of microwave bursts, Solar Phys. 44:155.

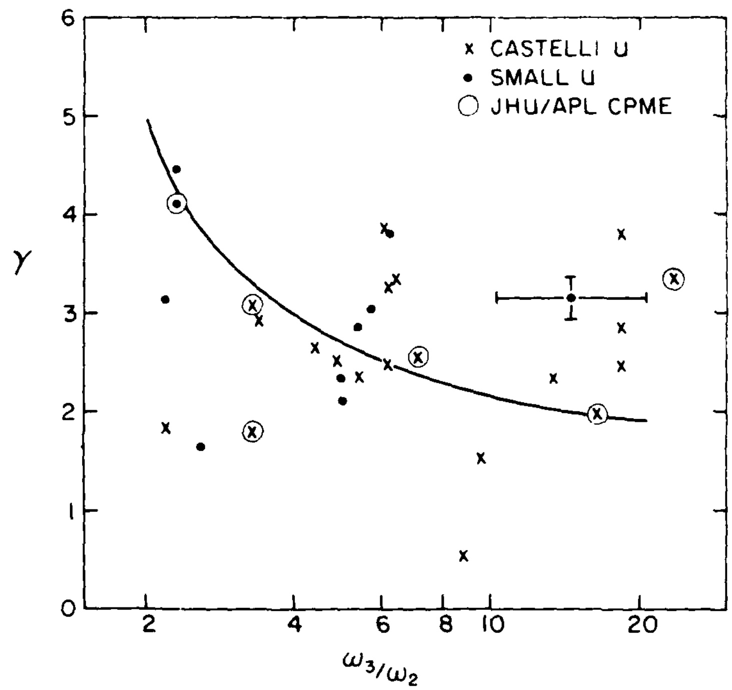

Figure 5. The Proton Differential Power-law Exponent γ Plotted Against ω_3/ω_2, the Ratio of the Centimetric Peak Frequency to the Frequency at the Bottom of the U, for the Events of This Study. Events meeting the Castelli U-burst criteria ($\geq$1000 s.f.u. at ω_3) show no obvious difference from those of lower fluxes. Data from the JHU/APL CPME were used when the GSFC detector data were saturated. The solid curve is the best fit derived by Bakshi and Barron (1979)[16] to events prior to 1973.

peak fluxes, while the correlation coefficients of the peak microwave fluxes were comparable to those of the 1-8 Å peak fluxes.

The substantially higher correlations found for the high-frequency time-integrated flux densities appear consistent with the proposition that the energetic electrons responsible for the microwave bursts are produced along with the energetic protons observed later in space. Uncertainties in the estimates of the time-integrated microwave flux densities of up to a factor of 2 and variations among events in the electron and proton energy spectra, the average ambient magnetic fields containing the electrons, and coronal and interplanetary proton propagation conditions, as well as possible flare misidentification, might well act to prevent the correlation coefficients from exceeding 0.7. On the other hand, the results may well be due solely to the BFS, so that, as discussed in the Introduction,

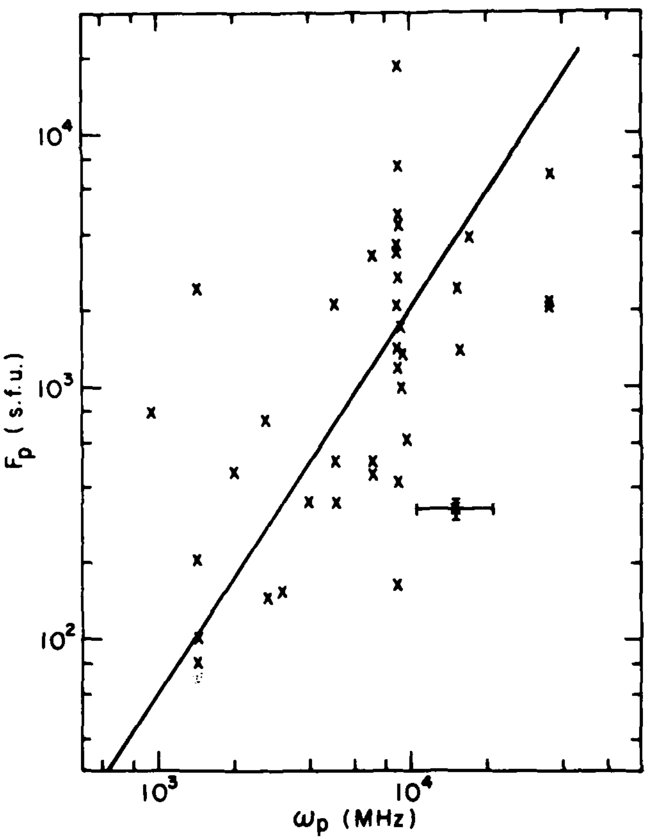

Figure 6. Plot of F_p Against ω_p for the U Bursts and C-spectral Events. The best fit is $F_p = 1.52\ 10^{-3} \times \omega_p^{1.54}$. Qualitatively similar results have been obtained for a large number of microwave bursts by Furst (1971)[36].

additional evidence is required to confirm a close relationship between electron and proton acceleration. Our examination of the correlations between γ and ω_3 or ω_3/ω_2 claimed by Akin'yan et al (1978a)[12] and Bakshi and Barron (1979),[16] respectively, yielded negative results. Because of the good correlation between time-integrated flux densities at high frequencies and peak proton fluxes, we also looked for a possible correlation between the ratio of the time-integrated flux densities at 8800 and 15400 MHz and the peak proton spectra, but the correlation was again essentially random ($r = -0.07$). The relationship between peak microwave flux density, F_p, and frequency of the peak flux density, ω_p, for proton flares, shown in Figure 6, is comparable to the results found for all microwave bursts and suggests nothing different about microwave bursts in proton flares. It also suggests

a BFS explanation for Croom's (1971a)[6] conclusion that burst spectra of proton flares have peak frequencies significantly higher than nonproton flare bursts, since the proton flares tend to be the largest flares. To summarize, the high-frequency integrated flux densities are the only parameters we have found which may exceed the BFS-induced correlations and suggest a physical coupling between the proton and electron acceleration processes. However, with a lack of any independent correlations, particularly those involving the proton spectra, the reality of the proposition that the protons and electrons are accelerated together is moot.

The modest correlation found for peak microwave flux densities has some interesting implications for earlier claims about the nature of proton acceleration. Hudson (1978)[38] and Belovskii and Ochelkov (1980)[39] have examined the size distributions of peak proton fluxes, I_p, and of peak microwave flux densities, F_p, and deduced a nonlinear relationship of the form $I_p \sim F_p^{\alpha}$, where Hudson derived $\alpha \sim 6$ and Belovskii and Ochelkov[39] $\alpha \sim 2 - 2.5$. The interpretation of this relationship is that the electrons, which produce the microwave emission, are accelerated by a mechanism different from that accelerating the protons and that proton acceleration operates much more efficiently in more energetic flares. Figure 3 provides an observational test of the nonlinear relationship deduced between I_p and F_p. The best fit of $\alpha = 1.40$ is well below both predictions of ~ 2 and ~ 6. In addition, the large scatter of the data show a distinct lack of a close dependence of proton flux on microwave flux. Even the smallest microwave bursts of ~10 s.f.u. can be associated with proton events. The results appear completely consistent with the BFS and do not support the results of Hudson[38] and Belovskii and Ochelkov.[39]

An additional reason for doubting their results is that proton flares may well be a separate class of flares, distinguished by the presence of coronal mass ejections (Kahler et al, 1978[40]). Pallavicini et al (1977)[41] have shown that flares associated with mass ejections are characterized by relatively large coronal volumes, small energy densities, and long time constants. Flares with and without mass ejections both show impulsive phases with characteristic microwave bursts (Kahler, 1981[40]), but the mechanical energy of large-scale mass motions dominates the flare radiative output by about two orders of magnitude, leaving the radiative

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38. Hudson, H.S. (1978) Threshold effect in second-stage acceleration, Solar Phys. 57:237.
39. Belovskii, M.N., and Ochelkov, Yu. P. (1980) Some properties of the generation of electromagnetic and corpuscular radiation of solar flares, Sov. Astron. 24:71.
40. Kahler, S.W. (1981) The development of x-ray flare onsets near active region filaments, Solar Phys. (in press).
41. Pallavicini, R., Serio, S., and Vaiana, G.S. (1977) A survey of soft x-ray flare images: the relation between their structure in the corona and other physical parameters, Astrophys. J. 216:108.

emissions from those flares a poor basis for estimating flare "importance" (Webb et al, 1980[42]). Thus, although proton flares may differ fundamentally from non-proton flares, the distinction may well not be obvious in the microwave range.

The good correlation between peak hard (E > 20 keV) X-ray and microwave flux densities (Kane, 1974[43]), together with the lack of a significant correlation between peak microwave fluxes and peak proton fluxes, suggest a poor correlation between peak hard X-ray fluxes and peak proton fluxes. An early study (Arnoldy et al, 1968[44]) using OGO I and III data suggested such a conclusion based on a number of proton events with no accompanying detectible hard X-ray events. The event of 4 October 1965, in particular, had a large peak proton flux and no detected X-ray event. However, Lin and Hudson (1976)[24] analyzed the OGO I and III data differently and concluded that all western hemisphere flares with a peak hard X-ray flux $> 5 \times 10^{-5}$ erg cm^{-2} s^{-1} gave rise to large proton events. They did not correlate the peak fluxes of the 10 hard X-ray events meeting that criterion with the associated peak proton fluxes, nor did they extend these results to proton events with fluxes smaller than 10 cm^{-2} s^{-1} at E > 10 MeV. There is therefore no evidence to indicate that peak hard X-ray fluxes correlate with peak proton fluxes any better than might be expected from the BFS. As in the case of peak microwave flux densities (Akin'yan et al, 1978a[12]), this does not preclude the use of hard X-ray events in proton event forecasting (Kane and Lin, 1980[45]).

The results of this study indicate that most correlations between proton fluxes and microwave parameters are explained within the context of the BFS and do not indicate that electrons and protons which escape the corona are accelerated in a common process. Only the time-integrated flux densities at 8800 and 15400 MHz give any evidence of a correlation based on such an acceleration process. The microwave burst peak spectra showed a diversity of spectral shapes, as reported earlier (Castelli and Tarnstrom, 1978[46]), no correlation with associated proton

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42. Webb, D.F., Cheng, C.C., Dulk, G.A., Edberg, S.J., Martin, S.F., McKenna-Lawlor, S., and McLean, D.J. (1980) Mechanical energy output of the 5 September 1973 flare, Solar Flares P.A. Sturrock (ed.) Colorado Associated University Press, Boulder, Colorado, 471.

43. Kane, S.R. (1974) Impulsive (flash) phase of solar flares: hard x-ray, microwave, euv and optical observations, Coronal Disturbances G. Newkirk, Jr. (ed.) **105**.

44. Arnoldy, R.L., Kane, S.R., and Winckler, J.R., (1968) Energetic solar flare x-rays observed by satellite and their correlation with solar radio and energetic particle emission, Astrophys J. **151**:711.

45. Kane, S.R., and Lin, R.P. (1980) Prediction of solar proton events using hard x-ray emission, Solar-Terrestrial Predictions Proceedings R.F. Donnelly (ed.) **3**, National Oceanic and Atmospheric Administration, D-34.

46. Castelli, J.P., and Tarnstrom, G.L. (1978) A Catalog of Proton Events 1966-1976 Having Non-classical Solar Radio Burst Spectra, AFGL-TR-78-0121, AD A060 816, Air Force Geophys. Lab., Hanscom AFB, MA 01731.

spectra, and no evidence of any special importance in the proton acceleration process. The present study was based on these reported peak flux densities and estimated durations of the bursts. Future studies considering significant microwave bursts with no associated proton events, an examination of the detailed time histories of the microwave bursts, and the role of metric type II bursts may help to elucidate the properties of the proton acceleration process.

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